Pentremites australis sp. nov., a New Lower Carboniferous (Tournaisian) Blastoid from New South Wales

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A new species of the blastoid *Pentremites* Say is described from the Lower Carboniferous Brushy Hill Limestone Member (middle Tournaisian) at Glenbawn Dam, New South Wales. *Pentremites australis* sp. nov. has a small pyriform (obconical) theca strongly pentagonal in plan view, with high pelvis and truncate vault. The anispiracle is excavated in an apparently undivided anal deltoid plate. Its short deltoids are barely visible and lancets are exposed full width forming petaloid ambulacra on the summit. Side plates abut the lancet and one hydrospire pore is present per side plate. Stratigraphically, *P. australis* is the earliest member of the genus, otherwise known from Mississippian (late Tournaisian) to Lower Pennsylvanian sequences of North and South America. The theca of the new species exhibits a combination of primitive and derived features.

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INTRODUCTION

Blastoids are a rare component of invertebrate faunas in the Carboniferous sequences of Australia and few have been described. *Nymphaeoblastus bancroftensis* McKellar, 1964, a fissiculate blastoid, was described by McKellar (1964) from the Lower Carboniferous Tellebang Formation, east of Monto, Queensland, in association with a prolific late Viséan *Rhipidomella fortimuscula* Zone brachiopod fauna. McKellar (1966) reviewed Etheridge's (1892) specimens from which he described the spiraculate *Malchiblastus australis* (Etheridge, 1892) from the Late Carboniferous Neerkol Formation. Campbell (1961) described a solitary radial plate from the Late Carboniferous Booral Formation, north of Newcastle, New South Wales, which he tentatively referred to *Pentremites*. Both the Neerkol and Booral Formations contain Namurian brachiopod faunas of the *Levipustula levis* Zone.

Pentremites Say, 1820 is noted for its relatively long stratigraphic range from the Mississippian (Osagean-Meramecian) to the Lower Pennsylvanian (Morrowan) and geographic distribution extending across North America into South America. *Pentremites* and the Pentremitidae have been the subject of numerous taxonomic revisions (Galloway and Kaska 1957; Macurda 1975; Macurda and Breimer 1977; Horowitz et al. 1981; Waters et al. 1985; Horowitz et al. 1986; Waters and Horowitz 1993) and eighteen species of *Pentremites* are presently known. *Pentremites kirki* Hambach, 1903 and *Pentremites elongatus* Shumard, 1855, in the Osagean (late Tournaisian - Tn 3: Jones, 1996) Burlington Limestone and its equivalents in North America, represent the earliest species of the genus (Waters et al. 1985).

This paper describing *Pentremites australis* sp. nov. from the Lower Carboniferous Brushy Hill Limestone Member at Glenbawn Dam, in the Hunter Valley of New South Wales, provides the first record of the genus outside the Americas and the oldest record of the genus. The limestone occurs near the base of the Dangarfield Formation, an 850 m thick sequence consisting of mudstone, siltstone, sandstone and calcarenite. Crinoids are locally prolific in calcarenites in the upper Dangarfield Formation, and include camerates and platycrinitids. Some of the camerate crinoids have been described by Lindley (1979, 1988).

Terminology used herein follows that of Beaver (1967) and Waters et al. (1985).

STRATIGRAPHY

The specimen of *Pentremites australis* was collected by J. Roberts from a quarry in the Brushy Hill Limestone Member near the southern abutment of Glenbawn Dam. Subsequent engineering works on the dam have resulted in changes to the quarry. A

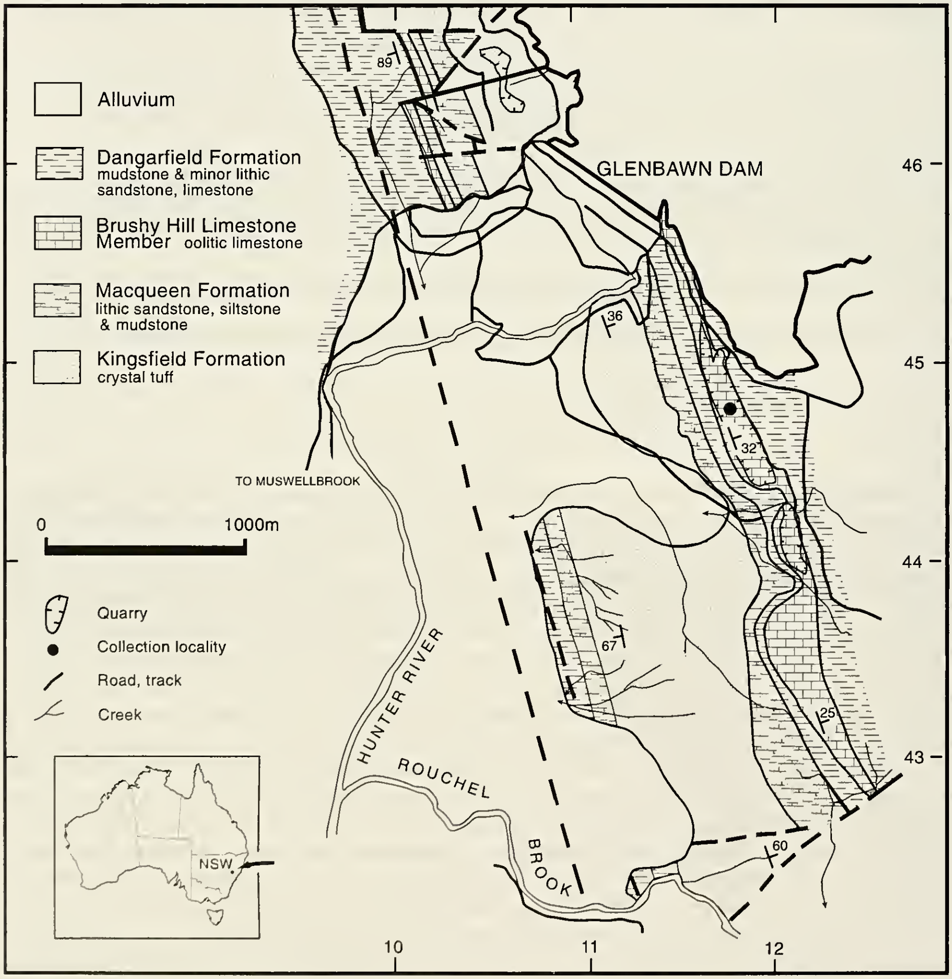


Figure 1. Geological map of the Glenbawn Dam district, upper Hunter Valley, New South Wales, showing collection horizon and locality. Modified after Mory (1978).

description of the original locality 1-9 is summarized from the field notes of J. Roberts (pers. comm.). Initial collections at the locality were made from reddish impure muddy oolitic limestone in about the middle of the Brushy Hill Limestone Member. Brachiopods were collected from the first bench and to a lesser extent the second bench of the (old) quarry. The red layer at the top of the first bench was collected for a conodont sample. Later collections were taken from unspecified positions within the quarry. Because it is not known to which collection the blastoid belongs, its precise collection level in the Brushy Hill Limestone Member is unknown.

The Brushy Hill Limestone Member was mapped by Roberts and Oversby (1974) as a thinly bedded oolitic limestone unit near the base of the Dangarfield Formation. Exposures of the member persist over a strike of 13 km along the western and eastern limbs of the NNW trending Brushy Hill Anticline, a structure confined to the similarly trending Brushy Hill Range, on the western foreshores of Lake Glenbawn, northeast of Muswellbrook (Fig. 1). The type section of the unit is measured in a quarry immediately southeast of Glenbawn Dam (Roberts and Oversby 1974). In the type section the member consists of 22 m of thinly crossbedded oolitic and skeletal limestone with minor mudstone (Mory 1978).

Mory (1978) recognised three lithological subdivisions of the Brushy Hill Limestone Member within the type area and the collection site of the blastoid specimen. The lowermost unit consists of 9 m of thinly cross-bedded oolitic limestone. Small, less than 0.3 mm diameter, oolites constitute over 90 percent of the allochems; macrofauna is scarce with only rare worn crinoid stem ossicles present. The lowermost unit is overlain by 3 m of massive skeletal oolitic limestone. The uppermost unit consists of 9 m of thinly bedded oolitic and skeletal limestones. Oolites constitute between 10 percent and 80 percent of the typically large (up to 1.25 mm) allochems. A diverse and abundant invertebrate fauna makes up the balance of the allochems.

The brachiopod fauna of the Brushy Hill Limestone Member at Glenbawn Dam is tentatively referred to the *Spirifer sol* Zone (Roberts and Oversby 1974) and is accompanied by conodonts of the lower *crenulata* Zone (Mory and Crane 1982), which indicate a correlation with the middle Tournaisian (Tn2a-2b) of Belgium, and the late Kinderhookian of North America (Jones 1996).

SYSTEMATIC PALAEONTOLOGY

Class BLASTOIDEA Say, 1825
Order PENTREMITIDA Matsumoto, 1929, emended Waters and Horowitz 1993

Remarks

Fay(1967) separated two orders of blastoids using the presence or absence of spiracles and hydrospire pores to separate the Spiraculata and Fissiculata, respectively. Horowitz et al. (1986) conclusion that the spiraculates are polyphyletic has resulted in an ordinal revision (Waters and Horowitz 1993). Order Pentremitida is an earlier ordinal name modified by Waters and Horowitz (1993) to include spiraculate blastoids with pyriform to godoniform thecae; four spiracles, each of which may be split by a septum, and an anispiracle; deltoid faces in most genera; and lancets partially to completely exposed. Waters and Horowitz (1993) suggested that *Pentremoblastus* Fay and Koenig, 1963 may constitute a separate unnamed order differing from Order Pentremitida only by its possession of a pyriform thecae. The unnamed order contains the single species *Pentremoblastus subovalis* Fay and Koenig, 1963. However, the genus *Pentremoblastus* is in need of revision (Waters and Horowitz 1993), with the type species *Pentremoblastus conicus* Fay and Koenig, 1963 being shown to be a fissiculate blastoid by Breimer and Macurda (1972).

The pyriform theca of the blastoid from the Brushy Hill Limestone Member suggests placement in either Order Pentremitida, or in Waters and Horowitz's (1993) unnamed order. The theca displays many morphological characters typical of the pentremitids, including four spiracles and an anispiracle, deltoid faces and completely exposed lancets (Waters and Horowitz 1993) and, given the uncertainties regarding the genus *Pentremoblastus* and the as yet unnamed order, it is classified in Order Pentremitida.

Family PENTREMITIDAE d'Orbigny, 1851
Genus PENTREMITES Say, 1820

Type species

Pentremites godoni (DeFrance, 1819), Late Mississippian, Illinois.

Diagnosis

A blastoid with a subpyriform to club-shaped theca. Anispiracle is present in an undivided anal deltoid plate. Lancet widely exposed, forming petaloid ambulacra; radials overlapping deltoids (Fay and Wanner 1967).

Remarks

Horowitz et al. (1986) described the characters that generally define the pentremitid condition to include four spiracles and an anispiracle, non-paired and ovate apertures, a single spiracular pore per side plate and pyriform or ovoid morphologies lacking an invaginated basalia. Fay and Wanner (1967) included ten genera in Family Pentremitidae but Horowitz et al. (1986), based on the conclusions of their review of the Order Spiraculata and Family Pentremitidae, have restricted the family to the genera *Pentremites* and *Strongyloblastus* Fay, 1962. Waters and Horowitz (1993) have tentatively added *Montanablastus* Sprinkle and Gutschick, 1990.

The blastoid from the Brushy Hill Limestone Member can be clearly distinguished from *Strongyloblastus* by its distinctive pyriform theca, elongate basals, number of spiracles and possession of an apparently undivided anal deltoid. Both *Montanablastus* and the Brushy Hill specimen have obconical thecae, but the former possesses a vault usually equal to or slightly longer than the pelvis, short basals and two anal deltoids.

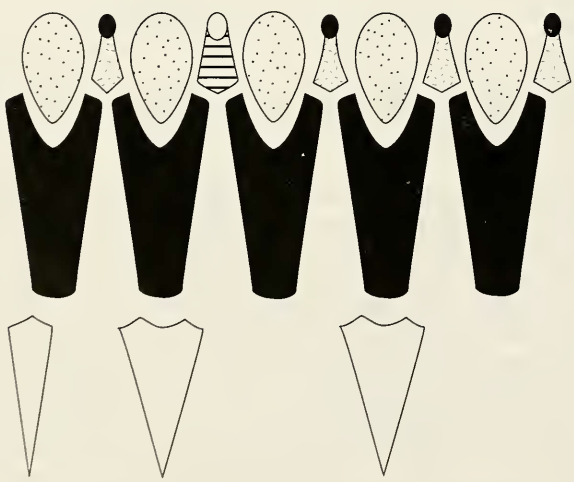
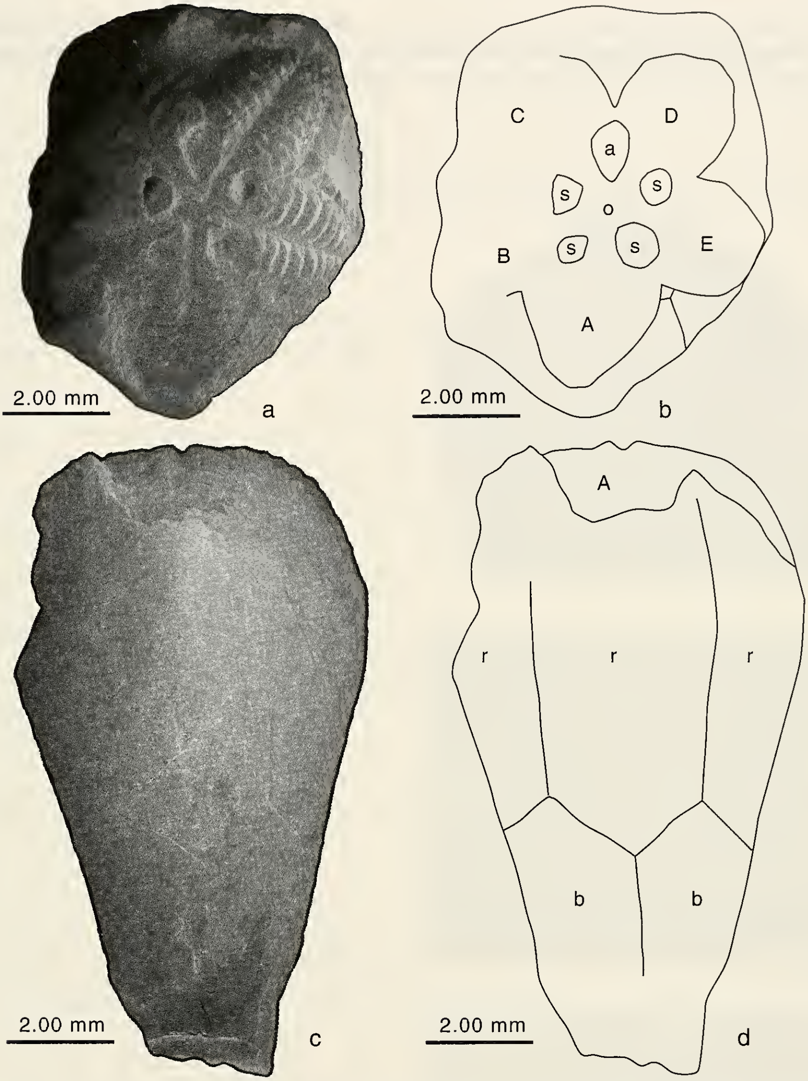


Figure 2. Plate diagram for *Pentremites australis* sp. nov. Deltoids are shown unobscured by overlapping ambulacra. (radials black; ambulacra light stipple; deltoid plates moderate stipple; anal plate hachured).



Figures 3a-d. *Pentremites australis* sp. nov. 3a,b, ANU 60108, oral view; 3c,d, ANU 60108, lateral view of A ray. [Explanation: a anal opening; d deltoid plate; dl deltoid lip; hp hydrospire pore; la lancet plate; o oral opening; r radial plate; rl radial limb; s spiracle; sd side plate; A-E A-E ray].

Pentremites australis sp. nov.

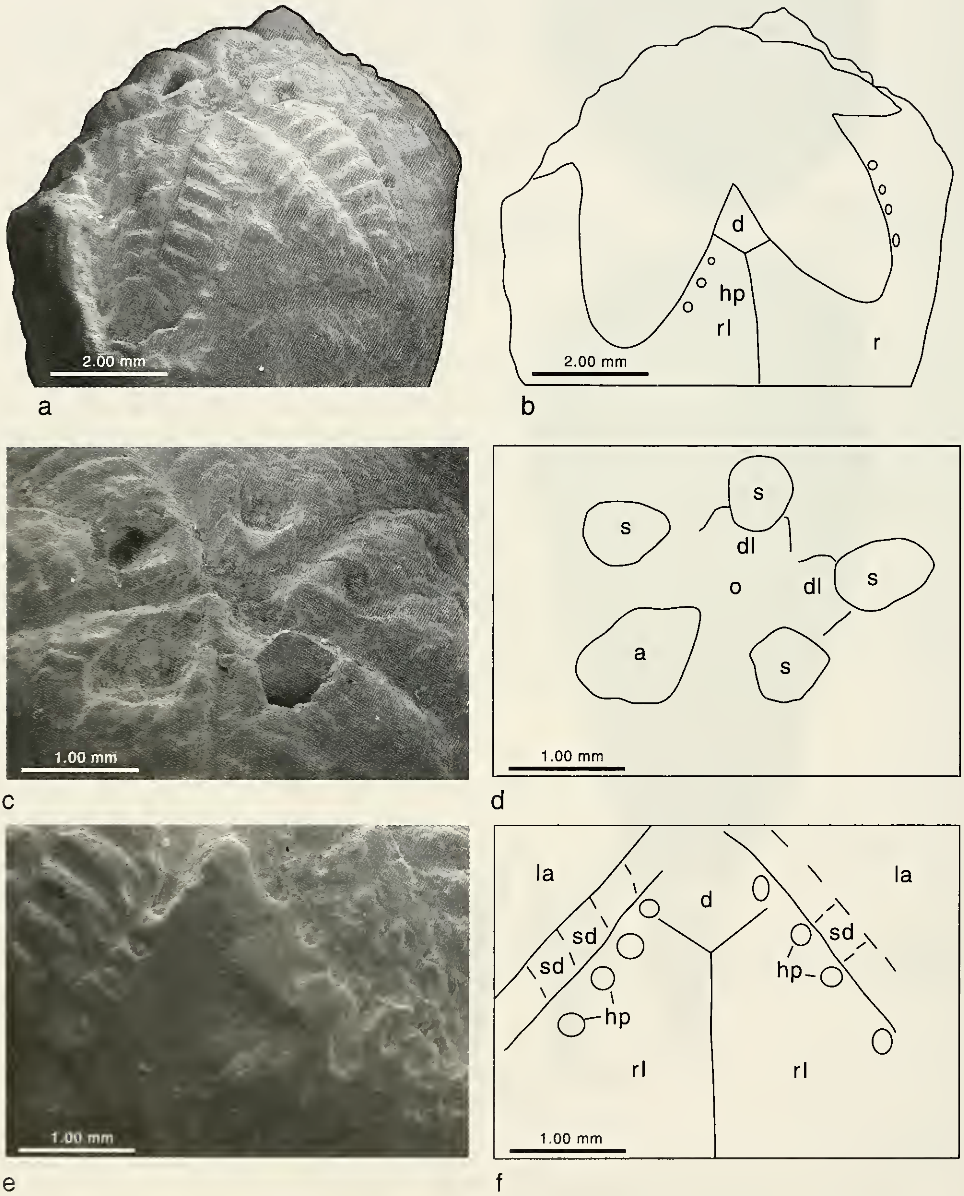
Figs 2, 3, 4

Synonymy

?*Pentremoblastus* sp., Roberts and Oversby 1974, p. 85.

Diagnosis

Small pyriform (obconical) theca, strongly pentagonal in plan view. High pelvis, representing much of the length of the theca, and a truncate vault. Both radials and basals are elongate. Four prominent ovoid-circular spiracles. Deltoids short and barely visible in lateral view. Lancets are exposed full width and restricted to summit, forming petaloid ambulacra. Side plates abut lancet; one pore between side plates.



Figures 4a-f. *Pentremites australis* sp. nov. 4a,b, ANU 60108, oblique view of A-E interray (foreground) and E-D interray, showing hydrospire pores along ambulacral margins and V-shaped suture between radials and deltoids in E-A interray; 4c,d, ANU 60108, details of oral area; 4e,f, ANU 60108, detail of D-E interray showing hydrospire pores, side plates and lancet margins. For explanation of symbols see Fig. 3.

Etymology

Latin *australis*, southern. The name *australis* is chosen to indicate the species is the southern-most occurrence of the genus *Pentremites*.

Material

Holotype ANU 60108, a nearly complete theca, from the Brushy Hill Limestone Member, Dangarfield Formation, on the southwestern side of Glenbawn Dam, New South Wales. Middle Tournaisian (Tn2a-2b). Housed in the Department of Geology, Australian National University, Canberra.

Description

Theca obconical in lateral view (Fig. 3c). Pelvis much longer than vault. Vault short and broad. Outline in plan view strongly pentagonal. Greatest width at aboral tips of ambulacra.

Basals three, representing 40 percent of lateral outline (Fig. 2). Azygous basal in A-B interray (normal position). Basals pentagonal in plan view with straight sides to the pentagon. Azygous basal quadrate in plan view with straight lateral and distal edges. Zygous basals pentagonal in plan view with straight sides. All basals covered by weak ornamentation of growth lines. Details of stem facet unknown. Stem unknown.

Radials five, large, relatively long and narrow, forming approximately 45 percent of lateral outline (Fig. 2). Radials heptagonal in plan view, with broad V-shaped sinus confined to adoral portion of radial. Lower edge of radial flat to weakly convex. Lateral edges straight. Upper edges convex. Width of radial greatest at aboral tip of ambulacral sinus. Radial limbs raised along ambulacral margins, small wide lip up to 0.3 mm long near origin of radials pointing obliquely outward and continuing pelvis profile. All radials covered by weak ornament of growth lines. Radial body pierced by hydrospire tubelets along ambulacral sinus (Figs 4a, 4e).

Deltoids four, small, narrow, together with anal deltoid forming the border to the peristome. Deltoids extending only a short distance down thecal surface, barely visible in lateral view; V-shaped suture between radials and deltoids forming 100 degree angle (Figs 4b, 4f). Detail on fractured surface along A-E interray suggests radials abut deltoids without obvious overlap (Fig. 4a). Four spiracles formed aborally to triangular deltoid lip which forms peristome, spiracles ovoid to circular, small (Figs 4c, 4d).

Anal deltoid apparently undivided. Anispiracle excavated near adoral tip which forms peristome (Fig. 4c). Anispiracle larger than spiracles, elliptical.

Ambulacra five, wide in plan view. Maximum width at level of spiracles. Ambulacra short and restricted to summit. Ambulacra contained within the radial sinus and are convex in cross-section. Side plates abut lancets. Surface of lancet bears median food groove and lateral grooves. Ambulacra do not extend to peristome.

Nature of side plates indefinite with edges between adjacent side plates and against lancet unknown (Figs 4e, 4f). Abmedial to side plates are hydrospire pores, one per plate, embedded in radial body. Hydrospire pores/tubelets clearly exposed in A, D and E rays.

Measurements

Length 11.1 mm; width 7.8 mm; pelvic angle 30 degrees; ambulacral length 3.3 mm; ambulacral width 1.0 mm; anispiracle length 1.0 mm; anispiracle width 0.7 mm; spiracle length 0.5 mm; spiracle width 0.5 mm.

Discussion

The stratigraphic position of *Pentremites australis* in the middle Tournaisian (Tn2a-2b) rocks of eastern Australia is lower than recorded for any other species of *Pentremites* but within the range of the family. *Strongyloblastus* is known from the Lower Carboniferous (Early-Middle Mississippian) of North America and *Montanablastus* from the Tournaisian (late Kinderhookian) of Montana (Sprinkle and Gutschick 1990).

Pentremites australis, *Pentremites kirki* and *Pentremoblastus subovalis* share characters typical of the pentremitid condition (Horowitz et al. 1986), and their distinctive pyriform thecae suggests these species are closely allied forms. All three species are known only from Tournaisian rocks and are clearly older than other pentremitids. *Pentremites australis* is distinctive with its gently curved vault and short ambulacra. By contrast, both *Pentremoblastus subovalis* and *Pentremites kirki* have subrounded to tightly parabolic vaults with ambulacra extending well down the theca.

Waters and Horowitz (1993) in their ordinal revision of the spiraculate blastoids discussed the significance of certain thecal morphological characters, interpreting them to be either primitive or derived. The theca of *P. australis* retains a combination of what they would interpret to be primitive and derived characters. Pyriform morphologies, such as that exhibited by *P. australis*, with high pelves and short or truncate vaults, are interpreted as a primitive character. Waters and Horowitz (1993) used ontogenetic studies of *Pentremites* to show that short deltoids, as in *P. australis*, are more primitive than very long deltoids. By contrast, exposed deltoid faces, also present in *P. australis*, are interpreted by Waters and Horowitz (1993) to be advanced over primitive deltoid crests. Based primarily on stratigraphic information, Waters and Horowitz (1993) also interpreted the broad, widely exposed ambulacra with side plates adjacent to lancets, as seen in *P. australis*, to be a derived character. Narrow ambulacra, with side plates overlapping lancets, represent the primitive condition. In summary, the new evidence from *P. australis* suggests that Waters and Horowitz's (1993) interpretation of thecal morphological characters of spiraculate blastoids as either primitive or advanced/derived may need revision.

BIOGEOGRAPHY

The biogeography of blastoids was reviewed by Waters (1990), who used the palaeogeographic maps of Scotese and McKerrow (1990) to show a southeastward migration of *Pentremites* from Tournaisian localities in Alaska and Alberta. By the Visean, *Pentremites* had migrated across the United States, where it was very widespread, and into South America. The presence of *Pentremites* in the middle Tournaisian of eastern Australia adds a new dimension to Waters' (1990) suggested migrations of the genus.

It is generally accepted that there is a marked similarity between the Lower Carboniferous invertebrate faunas of eastern Australia with those from North America and Europe (Campbell and McKellar 1969; among others). For the *Spirifer sol* Zone, identified from the Brushy Hill Limestone Member, Campbell and McKellar (1969) estimated that of the eighty genera of marine invertebrates known (bryozoans, corals, brachiopods, pelecypods, gastropods, cephalopods and trilobites), only nine are endemic to eastern Australia. Amongst the echinoderms, Campbell and Bein (1971) noted that the eastern Australian Lower Carboniferous crinoids show more affinity with North American faunas than do the co-occurring brachiopods. Webster and Jell (1999) noted that these affinities were at their greatest during the Tournaisian, with all Australian crinoid genera also known from North America and Europe.

The record of the blastoid *Pentremites* in the Tournaisian of eastern Australia lends further support to the established strong faunal affinities with North America and Europe. The apparent anomaly in the distribution of *Pentremites* presented by the eastern Australian occurrence, probably reflects what Waters (1990) describes as a collection bias that will undoubtely be rectified by further fieldwork.

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